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PCT / SE 2004 / 0 0 1 9 5 2

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(81)	*Designerade stater* *Designated states*	*AP: all, AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LI, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW*
(21)	*Patentansökningsnummer* *Patent application number*	*PCT SE03/02081*
(86)	*Ingivningsdatum* *Date of filing*	*2003-12-22*

Stockholm, 2004-12-29

För Patent- och registreringsverket
For the Patent- and Registration Office

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Original (for SUBMISSION) - printed on 22.12.2003 03:51:45 PM

0	For receiving Office use only	Ink. t. Patent- och reg.verket
0-1	International Application No.	PCT/SE 03 / 0 2 0 8 1 2003 -12- 22
0-2	International Filing Date	22 -12- 2003 Huvudfaxen Kassan
0-3	Name of receiving Office and "PCT International Application"	
0-4	Form - PCT/RO/101 PCT Request	
0-4-1	Prepared using	PCT-EASY Version 2.92 (updated 01.11.2003)
0-5	Petition The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty	
0-6	Receiving Office (specified by the applicant)	Swedish Patent Office (RO/SE)
0-7	Applicant's or agent's file reference	P18434WO
I	Title of invention	METHOD AND SYSTEM OF COMMUNICATIONS
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V	**Designation of States**	
V-1	Regional Patent (other kinds of protection or treatment, if any, are specified between parentheses after the designation(s) concerned)	AP: BW GH GM KE LS MW MZ SD SL SZ TZ UG ZM ZW and any other State which is a Contracting State of the Harare Protocol and of the PCT EA: AM AZ BY KG KZ MD RU TJ TM and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT EP: AT BE BG CH&LI CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL PT RO SE SI SK TR and any other State which is a Contracting State of the European Patent Convention and of the PCT OA: BF BJ CF CG CI CM GA GN GQ GW ML MR NE SN TD TG and any other State which is a member State of OAPI and a Contracting State of the PCT

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V-2	National Patent (other kinds of protection or treatment, if any, are specified between parentheses after the designation(s) concerned)	AE AG AL AM AT AU AZ BA BB BG BR BW BY BZ CA CH&LI CN CO CR CU CZ DE DK DM DZ EC EE EG ES FI GB GD GE GH GM HR HU ID IL IN IS JP KE KG KP KR KZ LC LK LR LS LT LU LV MA MD MG MK MN MW MX MZ NI NO NZ OM PG PH PL PT RO RU SC SD SE SG SK SL SY TJ TM TN TR TT TZ UA UG US UZ VC VN YU ZA ZM ZW	
V-5	**Precautionary Designation Statement** In addition to the designations made under items V-1, V-2 and V-3, the applicant also makes under Rule 4.9(b) all designations which would be permitted under the PCT except any designation(s) of the State(s) indicated under item V-6 below. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit.		
V-6	**Exclusion(s) from precautionary designations**	NONE	
VI	**Priority claim**	NONE	
VII-1	**International Searching Authority Chosen**	Swedish Patent Office (ISA/SE)	
VIII	**Declarations**	Number of declarations	
VIII-1	Declaration as to the identity of the inventor	-	
VIII-2	Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent	1	
VIII-3	Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application	-	
VIII-4	Declaration of inventorship (only for the purposes of the designation of the United States of America)	1	
VIII-5	Declaration as to non-prejudicial disclosures or exceptions to lack of novelty	-	

VIII-2-1	**Declaration: Entitlement to apply for and be granted a patent** Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent (Rules 4.17(ii) and 51bis.1(a)(ii)), in a case where the declaration under Rule 4.17(iv) is not appropriate: Name:	in relation to this international application TELEFONAKTIEBOLAGET L M ERICSSON (PUBL) is entitled to apply for and be granted a patent by virtue of the following:
VIII-2-1 (iv)		an assignment from LARSSON, Peter to TELEFONAKTIEBOLAGET L M ERICSSON (PUBL), dated 09 October 2003 (09.10.2003)
VIII-2-1 (iv)		an assignment from SIGNELL, Svante to TELEFONAKTIEBOLAGET L M ERICSSON (PUBL), dated 09 October 2003 (09.10.2003)
VIII-2-1 (ix)	This declaration is made for the purposes of:	all designations except the designation of the United States of America

VIII-4-1	**Declaration: Inventorship (only for the purposes of the designation of the United States of America)** Declaration of inventorship (Rules 4.17(iv) and 51bis.1(a)(iv)) for the purposes of the designation of the United States of America:	I hereby declare that I believe I am the original, first and sole (if only one inventor is listed below) or joint (if more than one inventor is listed below) inventor of the subject matter which is claimed and for which a patent is sought. This declaration is directed to the international application of which it forms a part (if filing declaration with application). I hereby declare that my residence, mailing address, and citizenship are as stated next to my name. I hereby state that I have reviewed and understand the contents of the above-identified international application, including the claims of said application. I have identified in the request of said application, in compliance with PCT Rule 4.10, any claim to foreign priority, and I have identified below, under the heading "Prior Applications," by application number, country or Member of the World Trade Organization, day, month and year of filing, any application for a patent or inventor's certificate filed in a country other than the United States of America, including any PCT international application designating at least one country other than the United States of America, having a filing date before that of the application on which foreign priority is claimed.
VIII-4-1 -1	Prior applications:	

		I hereby acknowledge the duty to disclose information that is known by me to be material to patentability as defined by 37 C.F.R. § 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the PCT international filing date of the continuation-in-part application. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.
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VIII-4-1 -1-6	Date: (of signature which is not contained in the request, or of the declaration that is corrected or added under Rule 26ter after the filing of the international application)	

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VIII-4-1-2-6	Date: (of signature which is not contained in the request, or of the declaration that is corrected or added under Rule 26ter after the filing of the international application):	

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IX	Check list	number of sheets	electronic file(s) attached
IX-1	Request (including declaration sheets)	8 ✓	–
IX-2	Description	16 ✓	–
IX-3	Claims	10 ✓	–
IX-4	Abstract	1 ✓	EZABST00.TXT
IX-5	Drawings	10 ✓	–
IX-7	TOTAL	45 ✓	
	Accompanying items	paper document(s) attached	electronic file(s) attached
IX-8	Fee calculation sheet	✓	–
IX-9	Original separate power of attorney	✓	–
IX-17	PCT-EASY diskette	–	Diskette
IX-19	Figure of the drawings which should accompany the abstract	2	
IX-20	Language of filing of the international application	English	
X-1	Signature of applicant, agent or common representative	Agneta Renefeldt	
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X-1-2	Name of signatory	Agneta Renefeldt	
X-1-3	Capacity	Agent	

FOR RECEIVING OFFICE USE ONLY

10-1	Date of actual receipt of the purported international application	22 -12- 2003
10-2	Drawings:	
10-2-1	Received	
10-2-2	Not received	
10-3	Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application	
10-4	Date of timely receipt of the required corrections under PCT Article 11(2)	
10-5	International Searching Authority	ISA/SE
10-6	Transmittal of search copy delayed until search fee is paid	

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11-1	Date of receipt of the record copy by the International Bureau	

PCT (ANNEX - FEE CALCULATION SHEET)

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12-23	Name and signature	Agneta Renefeldt Agneta Renefeldt

VALIDATION LOG AND REMARKS

13-2-3	Validation messages Names	Green? Applicant 1.:Facsimile No. missing
13-2-9	Validation messages Payment	Green? Please ensure that you have a valid deposit account with the receiving Office selected.

Method and system of communications

TECHNICAL FIELD OF THE INVENTION

The present invention relates to high data rate communications, and more especially it relates to line of sight, LOS, multiple input multiple output, MIMO, links, such as radio links and optical wireless communications links. For reasons of simplicity elements receiving or emitting electromagnetic fields are referred to as antenna elements as, e.g., light emitters and sensors are direct correspondences in light communications to antenna elements for radio wave communications.

BACKGROUND AND DESCRIPTION OF RELATED ART

High-speed wireline or fiber optic connections of backbone networks interconnecting nodes of a terrestrial radio access network are previously known. It is also known to interconnect radio base stations with microwave links providing interconnections of moderate data rates.

Increased antenna area of prior art microwave link antennas increases signal quality, but also increases irradiated microwave power as does transmission power increases. An increased antenna area can be achieved by arranging a plurality of smaller area antenna elements in an array.

Efficient modulations and signal constellations offer relieved power requirement, or improved performance if microwave power is maintained, as number of signal points in the signal constellation increases.

American Patent Application US2003/0125040 discloses a system for multiple-input multiple-output (MIMO) communication. A MIMO channel formed by N_T transmit antennas and N_R receive antennas is decomposed into N_C independent channels

also referred to as spatial sub-channels, where $N_C \leq \min\{N_T, N_R\}$. Data is processed prior to transmission based on channel state information.

American Patent Application US2002/0039884 reveals a radio communication system with a transmitter having a plurality of transmitter antennas and a receiver having at least one antenna. Thereby a plurality of paths with various characteristics are formed between the transmitter antennas and the at least one receiver antenna. Data is assigned one or more categories. Depending on categories and path characteristics, the data is mapped to one or more of the transmitter's parts and antennas.

American Patent Application US2002/0039884 describes a radio communication system with a transmitter having a plurality of transmitter antennas and a receiver having at least one antenna. Data tags indicate data importance or other requirements. Data is assigned one or more categories. Depending on categories and path characteristics, the data is mapped to one or more of the transmitter's parts and antennas.

3rd Generation Partnership Project (3GPP): *Technical Specification Group Radio Access Network, Physical layer aspects of UTRA High Speed Downlink Packet Access (Release 4), 3G TS 25.848 v4.0.0, France, March 2001,* describes MIMO open loop signal processing of MIMO transmitter and receiver in section 6.5.

Bell Labs Technical Journal, autumn 1996: G. Foschini, "Layered Space- Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas" shows that under fading conditions with statistically uncorrelated identically distributed propagation

channels, the bandwidth constrained channel capacity of a MIMO channel, C_{MIMO}, scales on average as

$$C_{MIMO} = C_{SISO} \cdot \min\{M, N\}, \qquad (1)$$

where C_{SISO} is channel capacity of a SISO channel. For a band limited (bandwidth B) AWGN (additive white gaussian noise) channel the SISO channel capacity equals

$$C_{SISO} = B \cdot \log_2(1 + SNR_{SISO}) \text{ [bits/s]}, \qquad (2)$$

where SNR_{SISO} is the SISO channel signal to noise ratio.

Figure 1 schematically illustrates N transmitter antenna elements «T_1, T_2,..., T_N» and M receiver antenna elements «R_1, R_2,..., R_M» in MIMO communications. Between the various transmitter and receiver antenna elements there are propagation channels «h_{11}, h_{12},... h_{1M},..., h_{NM}».

The individual propagation channels, that are SISO (Single Input Single Output) channels, form a MIMO channel.

C. Schlegel and Z. Bagley, *"Efficient Processing for High-Capacity MIMO Channels"* submitted to JSAC, MIMO Systems Special Issue: April 23, 2002 reveals estimation of optimum channel capacity of a MIMO system for a known MIMO-channel described by channel matrix $\mathbf{H}$ by means of singular value decomposition, SVD.

$$\mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V}^H = \mathrm{SVD}\{\mathbf{H}\}, \qquad (3)$$

where $\mathbf{U}$ and $\mathbf{V}$ are unitary matrices, $\mathbf{S}$ is a resulting diagonal matrix with singular values in the main diagonal, and $\mathbf{V}^H$ is a Hermitian transformed matrix $\mathbf{V}$.

None of the cited documents above discloses particular antenna configurations related to communications distance with line of sight, LOS, MIMO communications.

SUMMARY OF THE INVENTION

Next generation radio access networks are expected to be required to support peak user data rates in the order of magnitude of 30 Mbps - 1 Gbps. With a vast amount of base stations, it would be advantageous to interconnect base stations over radio links for flexibly connecting/disconnecting links of a mobile station active set of radio links with the base station as the mobile station moves.

Present radio link solutions do not offer sufficient data rates of aggregate user data, as to/from a base station, including a plurality of high user data rate at reasonable power levels for reasonably sized element antenna apertures.

Consequently, there is a need of antennas of large apertures providing required data rates at reasonable transmission power for reasonably sized element antenna apertures.

It is consequently an object of the present invention to achieve an antenna configuration for line of sight communication useful for providing low error rates at moderate transmission power within limits as may be required by due authorities.

It is also an object to achieve a system flexible to different transmission ranges and wavelength ranges.

An object is also to offer high data rates for low transmission power levels as regards antenna properties.

Another object is to achieve an antenna configuration adapted to particular communications distance and wave-length.

Finally, it is an object to relieve the dependency on tangible interconnections, such as wire lines or optical fibers, for interconnection of base stations or other nodes of a telecommunications system. Such interconnections are generally associated with great initial investment costs and maintenance costs.

These objects are met by a method and system of antennas configured for a particular communications distance over line of sight links providing multiple input multiple output communications links.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 schematically illustrates *N* transmitter antenna elements and *M* receiver antenna elements in MIMO communications.

Figure 2 schematically illustrates a spherical wave-front background to the invention.

Figure 3 illustrates example capacity versus SNR_{SISO} for four-element LOS MIMO linear array, according to the invention, and four-element linear array non-LOS MIMO.

Figure 4 illustrates a square grid LOS MIMO antenna array, according to the invention.

Figure 5 shows a linear LOS MIMO antenna array, according to the invention.

Figure 6 depicts a spatially oversampled antenna array, according to the invention.

Figure 7 demonstrates hexagonal antenna element packing, according to the invention.

Figure 8 has an antenna array with circular element packing, according to the invention.

Figure 9 displays a clustered directional hybrid with eight groups of clustered antenna elements for eight channels MIMO, according to the invention.

Figure 10 shows a clustered directional hybrid with four groups of clustered antenna elements for four channels MIMO, according to the invention.

Figure 11 illustrates a clustered directional hybrid with two groups of clustered antenna elements for two channels MIMO, according to the invention.

Figure 12 comprises plotted capacity per bandwidth vs. normalized SNR for MIMO communications with square grid LOS MIMO antennas for various levels of clustering at both receiver and transmitter side, according to the invention.

Figure 13 shows an LOS MIMO antenna array with director elements, according to the invention.

Figure 14 depicts schematically an LOS MIMO antenna with a grid of interconnected rods or tensed wires to which the antenna elements are attached, according to the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

In backbone networks based on wireless communications it is important to achieve capacity to handle data rates of aggregate traffic, where individual peak user data rates are in the order of 100 Mbps to 1 Gbps.

Fixed fiber optical networks are not always applicable. They are often associated with great costs, provide little or no flexibility and occupy extensive ground space.

Prior art Multiple Input Multiple Output, MIMO, communications systems most commonly are designed to utilize scattering and, therefore, requires a scattering environment.

The present invention is not dependent on such scatterers and suits line of sight communication very well. A theoretical reason for this is its exploitation of spherical wave fronts and associated phase differences.

Figure 2 schematically illustrates propagation paths and principles of the invention. Respective propagation paths «p_{11}», «p_{12}», «p_{13}» between a transmitter antenna «T1» and receiver antennas «R_1», «R_2», «R_3» differ slightly in length due to a spherical wave front property of the transmitted signal. The small differences in path lengths «δ_{11}», «δ_{12}», «δ_{13}» add to the communications distance D. With path p_{ij} as a reference for the communications distance, δ_{ij} equals zero. I.e. when p_{11} is selected as reference then $\delta_{11}=0$. The antenna configuration according to the invention essentially maximizes MIMO channel capacity for great signal to noise ratios, SNR, in respect of the spherical wave front property for LOS communications. This is in contrast to, e.g., maximizing antenna directivity as illustrated in and explained in relation to figure 12 below.

With each MIMO sub-channel operating close to its maximum theoretical performance, according to the configuration of the invention, great performance gains are achieved.

Figure 3 illustrates example capacity versus SNR_{SISO} for LOS MIMO and non-LOS MIMO (fading uncorrelated channels) for a four-element linear array. The gain of LOS MIMO as com-

pared to non-LOS MIMO in terms of capacity increase or SNR gain is the vertical or horizontal difference between the curves, respectively. The SNR gain implies, e.g., increased noise immunity or reduced transmission power requirement.

Radio Access Networks, RANs, are frequently realized with base stations connected in series, with at least one of the serialized base stations serving as an anchor to the core network. Consequently, the individual links between base stations may carry data traffic of a plurality of base stations. With individual peak user data-rates in the range of 100 Mbps – 1 Gbps required peak rates of data links between base stations could be expected to be in the range of 1–100 Gbps.

Prior art radio data links is not known to provide data rates of more than one Gbps for the spectrum efficiency achieved with the invention. The major two reasons for this are that there are practical limits on signal constellation sizes, practical and regulatory constraints on available radio spectrum, and power limits.

Prior art relies upon uncorrelated channels between the various antenna elements. This could e.g. be the case for channels fading due to scattering. However, the invention points out that exploitation of the spherical property of wave fronts results in ideal MIMO gain in absence of scatterers. According to the invention square grid LOS MIMO antenna array and linear LOS MIMO antenna arrays are preferred, see figures 4 and 5 respectively. This does not exclude circular or hexagonal packing as a means to increase antenna elements surface density as illustrated in figures 7 and 8 respectively. In the hexagonal packing of figure 7 the respective distances between (at most 6) near-

est neighboring antenna elements «Antenna element» are all essentially equal «d». Spatially oversampled and clustered antenna arrays, see figure 6 and 9 respectively, are preferred for some situations. Figures 10 and 11 show some other clustered directional hybrids for 16 antenna elements «Antenna element».

With reference to figures 9-11, while the total number of antenna elements, N, are kept constant equal to 16 elements the respective number of groups of elements, k, of the figures varies. In figure 9 there are eight groups with two antenna elements «Antenna element» each. Within each group the antenna elements «Antenna element» are positioned sufficiently close for signals to add coherently in phase, thereby generating a directivity gain. Figure 11 illustrates an example realization with four groups, each of four antenna elements «Antenna element». In figure 11, an example for N=16 and k=2 is illustrated. In the figures each group of antenna elements «Antenna element» generates a MIMO sub-channel. With N/k antenna elements for each MIMO sub-channel on receiver and transmitter side, the total achievable gain is $(N/k)^2$, since both sides contribute to the gain. If equivalent isotropic radiated power, EIRP, is at its maximum level allowed, the gain at transmitter side is achieved as a reduction of transmit power and not in increased received power or energy per symbol. Assuming an SNR gain of $(N/k)^2$ for grouped directional antennas with k groups, equations (1) and (2) transform into

$$C_{\text{clustered}} = B \cdot k \cdot \log_2\left(1 + \frac{N^2}{k^2}\text{SNR}_{\text{SISO}}\right) \text{ [bits/s]}. \qquad (4)$$

There are SNR ranges where MIMO communications with clustered elements antennas outperform MIMO with the same number of antenna elements, not being clustered. As noted in

figure 12 a channel capacity increase is achieved with clustering particularly for poor transmission conditions (small SNR). Figure 12, plots the channel capacity per bandwidth $C_{clustered}/B$ for MIMO communications with clustered antenna elements versus SNR «SNR_{SISO}» normalized to SISO communications conditions, and where k is the number of clusters of antenna elements at transmitter and receiver ends, $k \in [1,N]$. The figure illustrates performance for an example of 16 antenna elements according to equation (4), with SISO performance of N=1 antenna element antennas included for reference.

Typically high SNR conditions prevail in short range communications. Consequently, gain increase by unclustered MIMO communications with great number of antenna elements is preferred for short-range communications.

In figure 5, for an optimum MIMO system and for a communications distance D much greater than element separation d the distance $a=d(N-1)$ is specified by

$$a = (N-1)\sqrt{\frac{D\lambda}{N}} \qquad (5)$$

$$\approx \sqrt{D\lambda N}\,, \qquad (6)$$

where the approximation in equation (6) holds for great number of antenna elements N. For N=16 antenna elements «Antenna element», the approximation error is about 7%. Table 1 illustrates element separation, d, of a transmitter-receiver pair of linear MIMO antennas versus communications distance, D, at some example wavelengths, λ, equal to 3 mm, 7.9 mm and 42.9 mm.

Distance D [km]	Element separation d [m]		
	λ=3 mm	λ=7.9 mm	λ=42.9 mm
0.2	0.55	0.9	2.1
2	1.7	2.8	6.5
20	5.5	8.9	20.7
200	17.3	28.1	65.4

Table 1: Linear MIMO antenna, N=2.

For the square grid LOS MIMO antenna array in figure 4, the distance a, corresponding to that of equation (5) for linear arrays, is determined to $a=(\sqrt{N}-1)d$

$$a=(\sqrt{N}-1)\frac{\sqrt{D\lambda}}{\sqrt[4]{N}} \tag{7}$$

$$\approx\sqrt{D\lambda}\cdot\sqrt[4]{N}, \tag{8}$$

where the approximation in equation (8) holds for great number of antenna elements N. For N=16 antenna elements «Antenna element», the approximation error is about 33%. An important observation is that for the square grid LOS MIMO antenna array in figure 4 the distances a and d get relatively smaller in proportion to the fourth root of N, whereas for the linear array of figure 5 the distance dependency is proportional to the square root of N.

With the antenna area $A=a^2$, and using the approximation in equation (8), the MIMO channel capacity, $C_{MIMO}=N\cdot C_{SISO}$, expressed in terms of channel capacity for a SISO system, C_{SISO}, with the example design of figure 4 according to the invention is

$$C_{MIMO} \approx \left(\frac{A}{D\lambda}\right)^2 C_{SISO} \tag{9}$$

In figure 4 and equation (7) the antenna elements «Antenna element» are assumed to be electrically active elements, supplying a voltage or current to a receiver. However, as illustrated below basically the same distance relations hold for antenna elements being directors guiding received electromagnetic field to electrically active antenna elements.

Figure 13 illustrates an alternative realization with director elements «Director» mounted on supports «Supports». The directors «Director» direct electromagnetic fields received and electromagnetic fields to be transmitted, preferably with one director per electrically active antenna element «Active elements». Preferably the directors «Director» are pure reflectors but can also be made of dielectric material. The supports «Supports» are designed not to shadow, or only have a small shadowing impact on, the electrically active antenna elements «Active elements». The positioning of the directors is preferably in accordance with equation (5) and (7) for a linear and square grid LOS MIMO antenna respectively. The relevant distance d is essentially equal to the separation distance of the projection of the directors onto a plane, the plane being perpendicular to the LOS transmission path to the other receiver/transmitter end. Advantages achieved by the realization of figure 13 in addition to those mentioned above are, e.g., simplified wiring of the antenna elements and the antenna elements spanning a smaller distance range thereby being mechanically robust. Also, by adjusting the directors the electrically active antenna elements need not always be repositioned even if communications distance changes.

The dependency of a, A and d on D for an LOS MIMO antenna has practical implications, addressed by the invention. An obvious solution to the problem of getting a, to the communications distance D, appropriately matched element distance, d, is to manufacture custom-made antennas. From a cost perspective, however, a more attractive solution is manufacturing of a set of antenna models for MIMO communications, each designed for a range of communications distances D, and upon installation selecting an antenna model within the set that best matches the communications distance. Another embodiment is realized by individually adjustable antenna elements. Preferably this is realized by a grid «Grid» of interconnected rods or tensed wires to which the antenna elements «Antenna element» are attached as illustrated in figure 14. The wires or rods are preferably connected to a frame «Frame». Models that are electromechanically adjustable comprise electromechanical motors to which the rods are connected, such that the rods to which the antenna elements «Antenna element» are attached may move along the frame. A further embodiment of adapting an LOS MIMO antenna to communications distance D uses spatial oversampled antennas as schematically illustrated in figure 6 and activating the antenna elements by signal processing providing best performance at actual communications distance. The particular element distribution may be varied, e.g. as illustrated in figures 7 and 8. An important issue of the invention is that active elements are distributed such that their mutual distances reflects communications distance (distance between transmit and receive antennas) and wavelength such that the spherical properties of the radio wave can be exploited.

It is observed that as transmitter and receiver antennas form an antenna pair for a communications link, the element

distance d of e.g. a transmitter antenna can be reduced if the element distance of the corresponding receiver antenna of the communications link is increased in proportion to the distance reduction of the transmitter antenna. If element distance of receiver antenna, d_R, are reduced in relation to d, transmitter-side antenna element distance, d_T, should be increased (in relation to d) in proportion thereto. Consequently, the distance d of equations (5) and (7) is the geometrical average $\sqrt{d_R \cdot d_T}$ of receiver and transmitter antenna element distances d_R and d_T, respectively.

The invention does not only cover planar antenna configurations, but also three-dimensional configurations as illustrated in figures 15-17. Figure 15 illustrates a two-layer square grid LOS MIMO antenna with two layers of antenna elements each on a square grid. Figures 16 and 17 illustrate realizations with equal distance between all nearest neighboring antenna elements. In figure 16 the antenna elements are positioned to the vertices of a cube and in figure 17 the antenna elements are positioned to the vertices of a tetrahedron.

Various embodiments of the invention also cover different realizations of signal processing at transmitter and receiver ends. The processing is necessary for adaptation to prevalent channel conditions. At receiver or transmit side, determining channel singular values as described in relation to equation (3) and singular value decomposition can be achieved by digital signal processing of base band signals. If determined at transmitter side, information on channel matrix, $\mathbf{H}$, need to be transferred from receiver side, or the channel matrix otherwise estimated at transmitter side, see figure. For a 2×2 channel matrix, singular value decomposition can also be achieved by a 3-dB hy-

brid to perform multiplication or weighting as need be, operating on high-frequency signals. Also, for channel matrices greater than 2X2 a generalization of a 3-dB hybrid, a Butler matrix directional coupler, may be used. A further embodiment realizes the processing by means of an arrangement of microstrip or waveguides, also operating on high-frequency signals. At receiver side, channel equalization requires processing. This processing can be performed by any of the processing realizations described for transmitter side, or received signal can be equalized by means of zero forcing, for which the received signal being multiplied by the inverse matrix of channel matrix **H**, or by means of minimum mean square error, MMSE, for which the mean square error is minimized, the various processing realizations giving rise to further embodiments.

If there is multipath propagation, this is preferably incorporated into the singular value decomposition at transmitter side through feedback information. Corresponding information can also be derived through channel reciprocity if the reverse direction channel matrix is determined at transmitter side (the transmitter side also comprising radio receiver). Another solution comprises a self-tuning antenna, optimizing performance at receiver side, transmitter side or both. The antenna element positioning is then adapted to channel propagation properties corresponding to a measured channel matrix, **H**. This can be achieved by, e.g. a stochastic gradient algorithm. Particularly for fixed positioned antenna elements, they may require the antenna elements to be re-distributed for optimum performance. For an electromechanically adjustable element antenna the optimization can be achieved by automatic position adjustments of the antenna elements. The different solutions to multipath propagation can also be combined.

The concept of the present invention combines well with other known means to increase throughput, such as transmission at both vertical and horizontal polarization or transmission at left-hand and right-hand circular polarization, or different coding of different sub-channels depending on their respective channel quality, which further demonstrates the usefulness of the invention. Such combinations are also within the scope of this invention.

The invention is not intended to be limited only to the embodiments described in detail above. Changes and modifications may be made without departing from the invention. It covers all modifications within the scope of the following claims.

CLAIMS

1. A method of antenna configuration characterized in that the antenna comprising a plurality of antenna elements is configured such that the antenna elements separation is set in relation to communications distance.

2. The method according to claim 1 characterized in that the antenna is configured such that the antenna elements separation is set in relation to communications wavelength.

3. The method according to claim 1 or 2 characterized in that the antenna configuration maximizes MIMO channel capacity.

4. The method according to claim 1 or 2 characterized in that for a linear antenna the antenna elements separation is set in relation to $\sqrt{D\lambda/N}$, where D is communications distance, λ is communication wavelength and N is number of antenna elements.

5. The method according to claim 1 or 2 characterized in that for a square grid antenna the antenna elements separation is set in relation to $\sqrt{D\lambda/\sqrt{N}}$, where D is communications distance, λ is communication wavelength and N is number of antenna elements.

6. The method according to claim 5 characterized in that $N=n^2$ for n an integer greater than 1.

7. A method of antenna configuration characterized in that an antenna comprising a plurality of clusters of one or more antenna elements is configured such

that the clusters are separated by a distance set in relation to communications distance.

8. The method according to claim 7 characterized in that the antenna is configured such that the clusters of antenna elements are separated by a distance set in relation to communication wavelength.

9. The method according to claim 7 or 8 characterized in that for a linear antenna the clusters are separated by a distance set in relation to $\sqrt{D\lambda/L}$, where D is communications distance, λ is communication wavelength and L is number of clusters.

10. The method according to claim 7 or 8 characterized in that for a square grid antenna the clusters are separated by a distance set in relation to $\sqrt{D\lambda/\sqrt{L}}$, where D is communications distance, λ is communication wavelength and L is number of clusters.

11. The method according to claim 10 characterized in that $L=l^2$ for l an integer greater than 1.

12. The method according to claim 7 or 8 characterized in that the antenna elements within a cluster are separated by a distance smaller than the smallest distance between clusters.

13. The method according to claim 1 or 2 characterized in that the antenna configuration is three-dimensional.

14. The method according to claim 13 characterized in that the antenna configuration comprises two layers, where each layer comprises a planar arrangement of antenna elements on a square grid.

15. The method according to claim 13 characterized in that the antenna configuration comprises antenna elements positioned equidistant in a three-dimensional space.

16. The method according to claim 15 characterized in that the antenna elements are positioned to vertices of a cube.

17. The method according to claim 15 characterized in that the antenna elements are positioned to vertices of a tetrahedron.

18. The method according to any of claims 1, 2, 7 and 8 characterized in that the antenna elements are fed with signals processed according to singular value decomposition for a transmission channel over the communications distance.

19. The method according to any of claims 1, 2, 7 and 8 characterized in that the signals received from the antenna elements are processed according to zero forcing for a transmission channel over the communications distance.

20. The method according to any of claims 1, 2, 7 and 8 characterized in that the signals received from the antenna elements are processed to minimize mean square error for a transmission channel over the communications distance.

21. The method according to any of claims 1, 2, 7, 8, 18 and 19 characterized in that signal processing of signals received or to be transmitted is performed at high-frequency.

22. The method according to claim 21 characterized in that the processing is performed by one or more 3-dB hybrids.

23. The method according to claim 21 characterized in that the processing is performed by one or more Butler matrix directional couplers.

24. The method according to claim 21 characterized in that the processing is performed by an arrangement of microstrip.

25. The method according to claim 21 characterized in that the processing is performed by an arrangement of waveguides.

26. The method according to any of claims 1-25 characterized in that the antenna configuration is a radio antenna configuration.

27. The method according to any of claims 1-25 characterized in that the antenna configuration is a configuration of sensors or actuators for optical communications.

28. An antenna configuration characterized by the antenna comprising a plurality of antenna elements configured such that the antenna elements separation is set in relation to communications distance.

29. The antenna configuration according to claim 28 characterized by the antenna is configured such that the antenna elements separation is set in relation to communication wavelength.

30. The antenna configuration according to claim 28 or 29 characterized in that the antenna configuration maximizes MIMO channel capacity.

31. The antenna configuration according to claim 28 or 29 characterized by the antenna elements separation is set in relation to $\sqrt{D\lambda/N}$, where D is communications distance, λ is communication wavelength and N is number of antenna elements, and wherein the antenna configuration is a linear antenna configuration.

32. The antenna configuration according to claim 28 or 29 characterized by the antenna elements separation is set in relation to $\sqrt{D\lambda/\sqrt{N}}$, where D is communications distance, λ is communication wavelength and N is number of antenna elements, and wherein the antenna configuration is a square grid antenna configuration.

33. The antenna configuration according to claim 32 characterized in that $N=n^2$ for n an integer greater than 1.

34. The antenna configuration according to claim 28 or 29 characterized by the antenna configuration being three-dimensional.

35. The antenna configuration according to claim 34 characterized by the antenna configuration comprising two layers, where each layer comprises a planar arrangement of antenna elements on a square grid.

36. The antenna configuration according to claim 34 characterized by the antenna configuration comprising antenna elements positioned equidistant in a three-dimensional space.

37. The antenna configuration according to claim 36 characterized by the antenna elements being positioned to vertices of a cube.

38. The method according to claim 36 characterized by the antenna elements being positioned to vertices of a tetrahedron.

39. An antenna configuration characterized by an antenna comprising a plurality of clusters of one or more antenna elements configured such that the clusters are separated by a distance set in relation to communications distance.

40. The antenna configuration according to claim 39 characterized by the antenna being configured such that the clusters of antenna elements are separated by a distance set in relation to communication wavelength.

41. The antenna configuration according to claim 39 or 40 characterized by the clusters being separated by a distance set in relation to $\sqrt{D\lambda/L}$, where D is communications distance, λ is communication wavelength and L is number of clusters, and wherein the antenna configuration is a linear antenna configuration.

42. The antenna configuration according to claim 39 or 40 characterized by the clusters being separated by a distance set in relation to $\sqrt{D\lambda/\sqrt{L}}$, where D is communications distance, λ is communication wavelength and L is number of clusters and wherein the antenna configuration is a square grid antenna configuration.

43. The antenna configuration according to claim 42 c h a r a c t e r i z e d i n that $L=l^2$ for l an integer greater than 1.

44. The antenna configuration according to claim 39 or 40 c h a r a c t e r i z e d i n that the antenna elements within a cluster are separated by a distance smaller than the smallest distance between clusters.

45. The antenna configuration according to any of claims 28, 29, 39 and 40 c h a r a c t e r i z e d b y one or more antenna element feeders adapted to feed the antenna elements with signals processed according to singular value decomposition for a transmission channel over the communications distance.

46. The antenna configuration according to any of claims 28, 29, 39 and 40 c h a r a c t e r i z e d b y one or more processing elements adapted to process signals received from the antenna elements according to zero forcing for a transmission channel over the communications distance.

47. The antenna configuration according to any of claims 28, 29, 39 and 40 c h a r a c t e r i z e d b y one or more processing elements adapted to process signals received from the antenna elements to minimize mean square error for a transmission channel over the communications distance.

48. The antenna configuration according to any of claims 28, 29, 39, 40, 45 and 46 c h a r a c t e r i z e d b y one or more processing elements adapted to process at high-frequency signals received or to be transmitted.

49. The antenna configuration according to claim 48 characterized by the one or more processing elements being one or more 3-dB hybrids.

50. The method according to claim 21 characterized by the one or more processing elements being one or more Butler matrix directional couplers.

51. The antenna configuration according to claim 48 characterized by the one or more processing elements being an arrangement of microstrip.

52. The antenna configuration according to claim 48 characterized by the one or more processing elements being an arrangement of waveguides.

53. The antenna configuration according to any of claims 28-52 characterized by the antenna elements being electrically active elements.

54. The antenna configuration according to any of claims 28-52 characterized by the antenna elements being directors.

55. The antenna configuration according to claim 54 characterized by the directors being reflectors.

56. The antenna configuration according to any of claims 28-55 characterized by the antenna elements being arranged circular symmetrically.

57. The antenna configuration according to any of claims 28-55 characterized by the antenna elements being arranged in a hexagonal pattern.

58. The antenna configuration according to any of claims 28-55 c h a r a c t e r i z e d b y the antenna elements being mounted on position adjustable rods or wires.

59. The antenna configuration according to claim 58 c h a r a c t e r i z e d b y the position adjustable rods or wires being electromechanically adjustable.

60. The antenna configuration according to claim 59 c h a r a c t e r i z e d i n that the adjustable position is adaptive to propagation channel properties corresponding to a measured channel matrix.

61. The antenna configuration according to any of claims 28-57 c h a r a c t e r i z e d b y the antenna configuration being adapted to a predetermined range of communications distances.

62. An antenna configuration c h a r a c t e r i z e d b y the antenna configuration comprising a plurality of antenna elements, of which a subset forms an active set of antenna elements, the active antenna elements forming an antenna configuration according to any of claims 28-57.

63. The antenna configuration according to any of claims 28-62 c h a r a c t e r i z e d i n that the antenna configuration is a radio antenna configuration.

64. The antenna configuration according to any of claims 28-62 c h a r a c t e r i z e d i n that the antenna configuration is a configuration of sensors or actuators for optical communications.

65. A communications system c h a r a c t e r i z e d b y means for carrying out the method in any of claims 1-25.

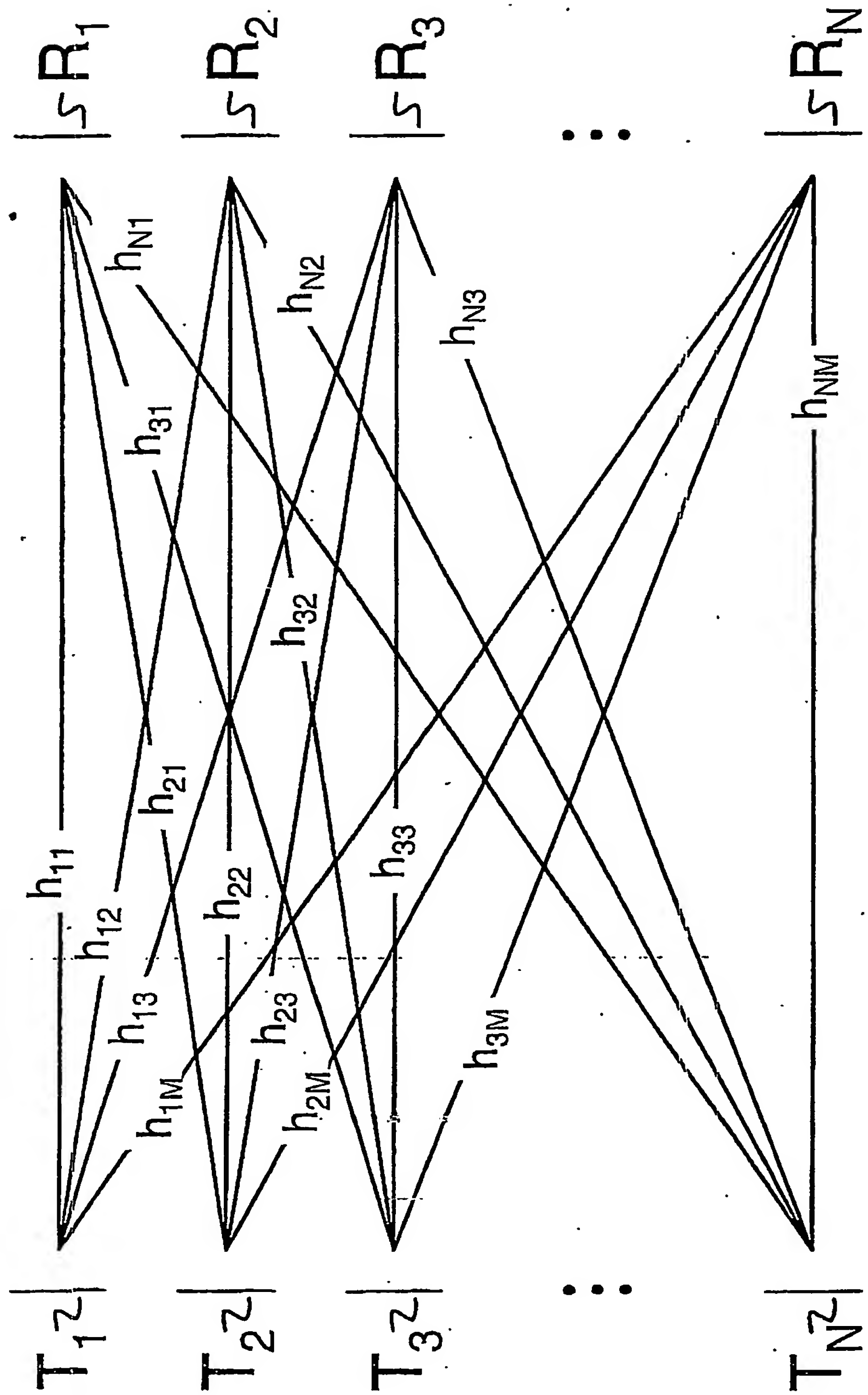
66. A communications system characterized by a plurality of devices in any of claims 28-62.

67. The communications system according to claim 66 characterized in that the antenna elements distances are set different for a first and a second antenna, the two antennas operating in pair, such that the geometrical average of the elements distance of the first antenna, d_1 and the elements distance of the second antenna, d_2, is the effective antenna elements distance.

ABSTRACT

The present invention relates to high data rate communications, and more especially it relates to line of sight, LOS, multiple input multiple output, MIMO, communications links and antenna configuration for LOS MIMO links, particularly radio links and optical wireless links.

Figure for publication with abstract: figure 2.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R2
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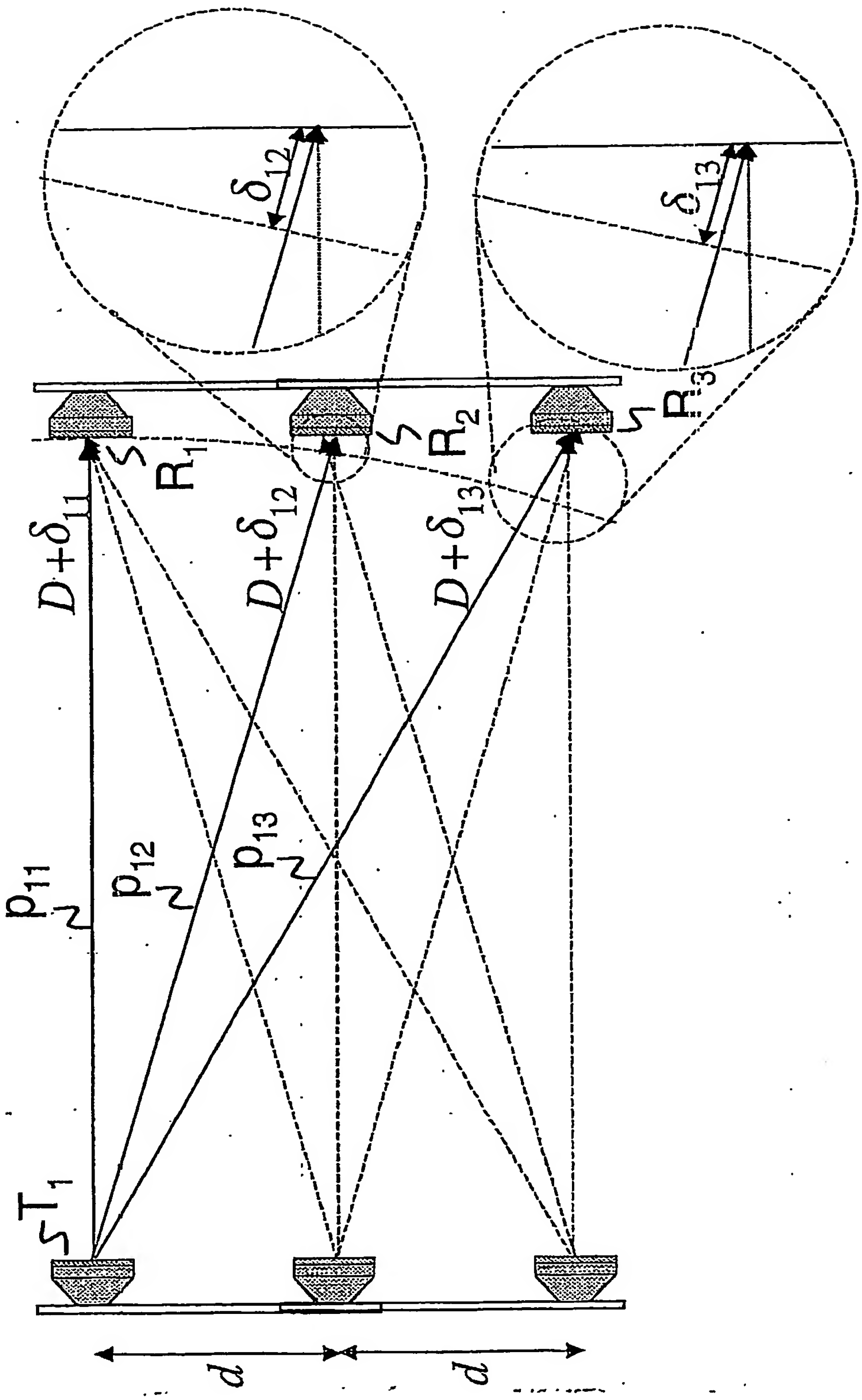
h33
h3M
hN1
hN2
hN3
hNM

Fig. 1


δ_{12}
δ_{13}
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R_2
R_3
$D+\delta_{11}$
$D+\delta_{12}$
$D+\delta_{13}$
p_{11}
p_{12}
p_{13}
T_1
d
d

Fig. 2

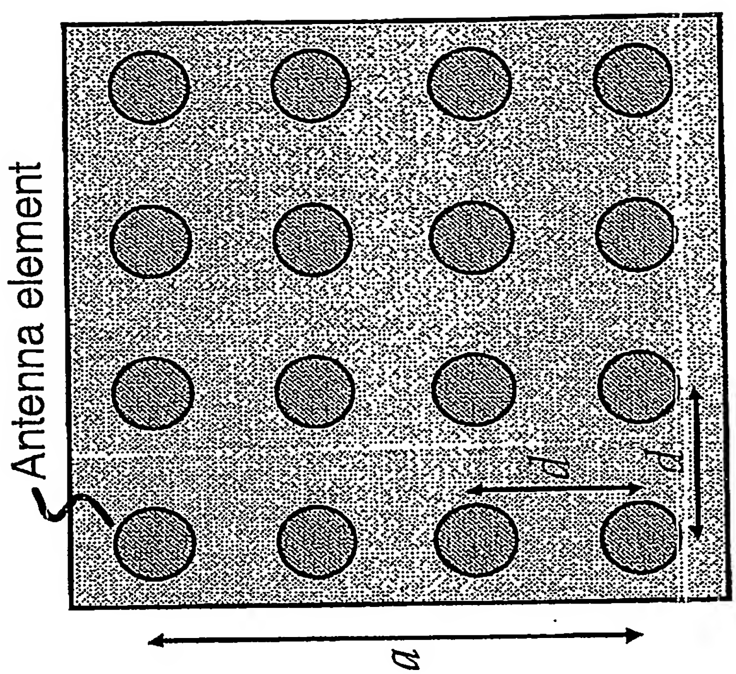
Antenna element
d
d
a

Fig. 4

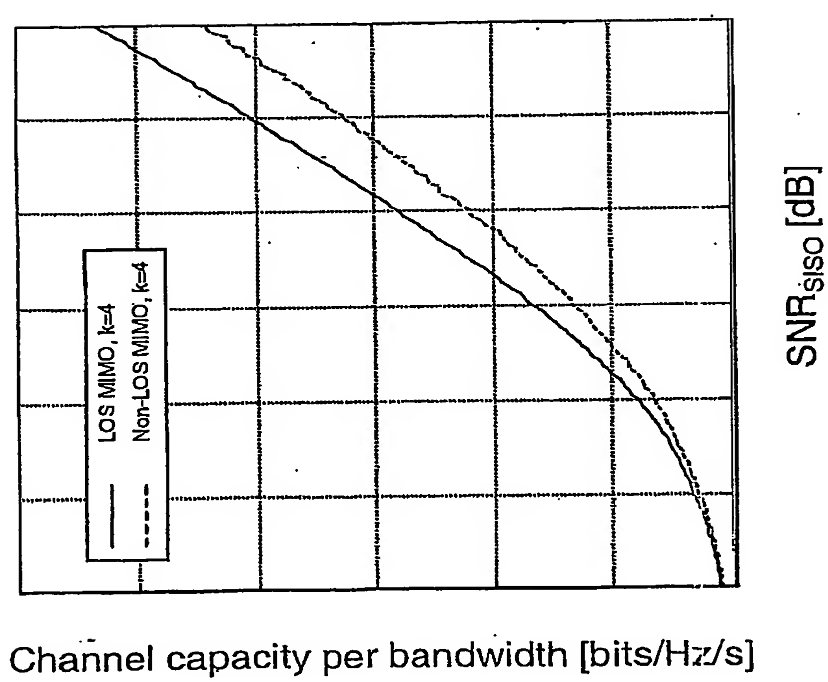
LOS MIMO, k=4
Non-LOS MIMO, k=4
SNR$_{SISO}$ [dB]
Channel capacity per bandwidth [bits/Hz/s]

Fig. 3

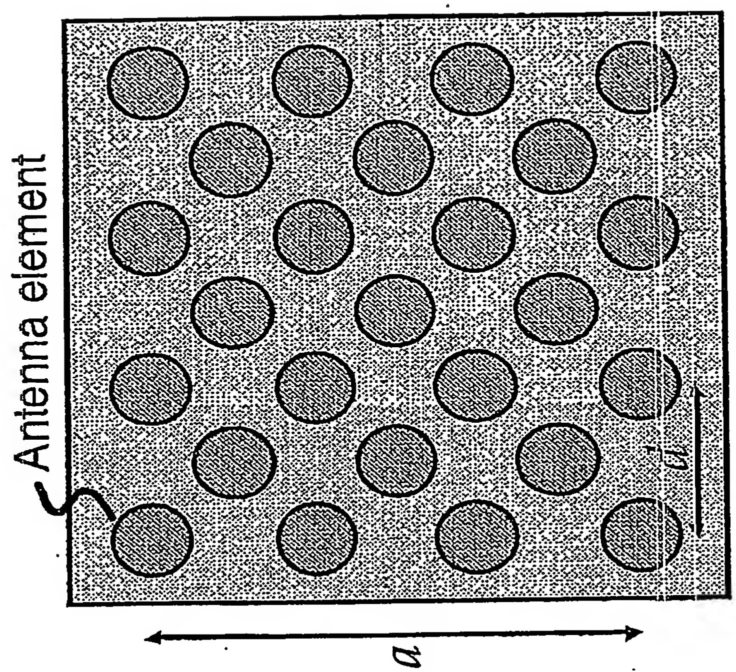

Fig. 6

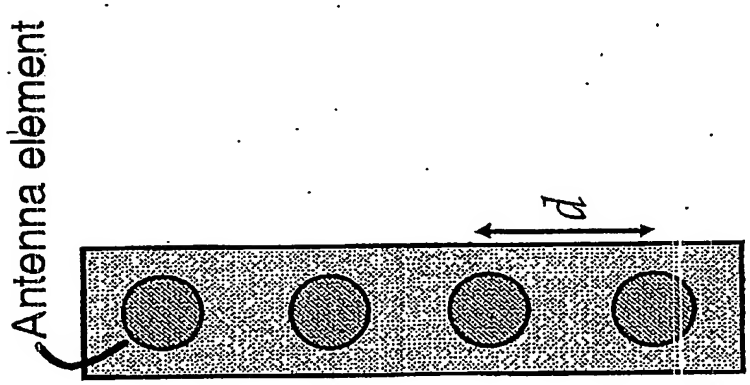

Fig. 5

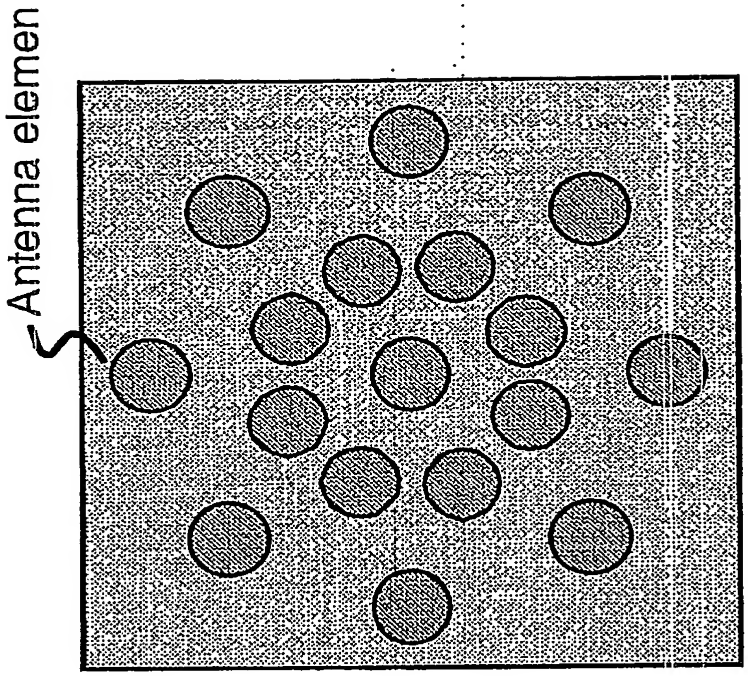

Fig. 8

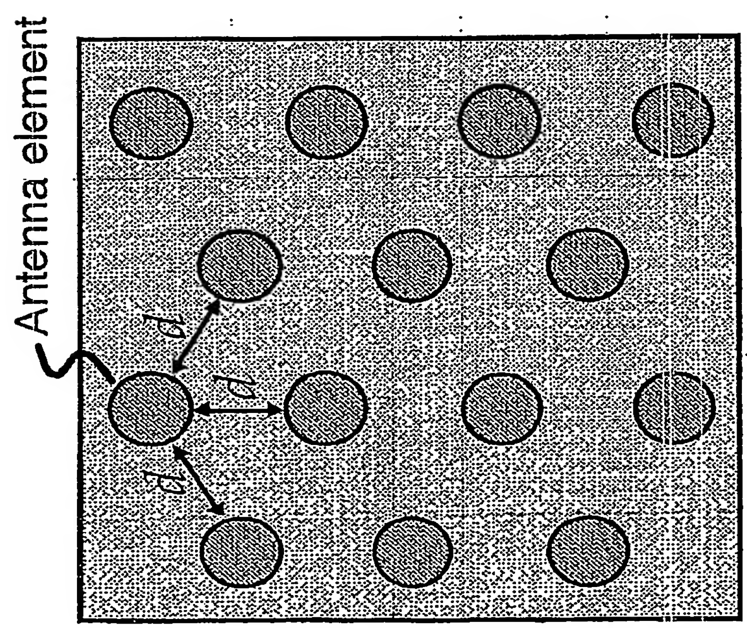

Fig. 7

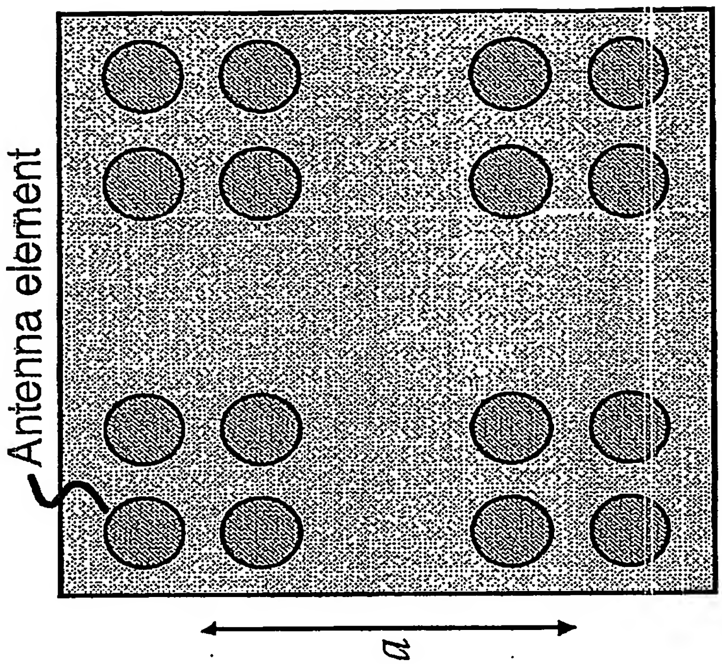

Fig. 10

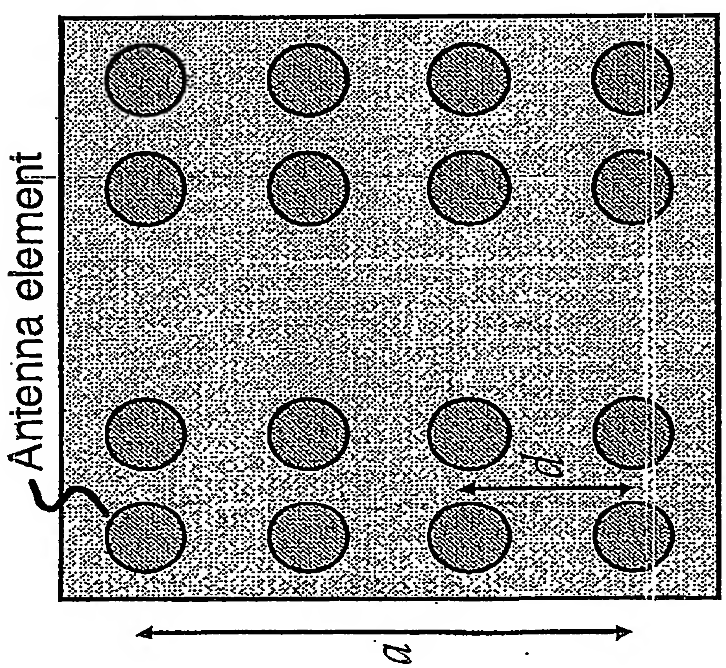

Fig. 9

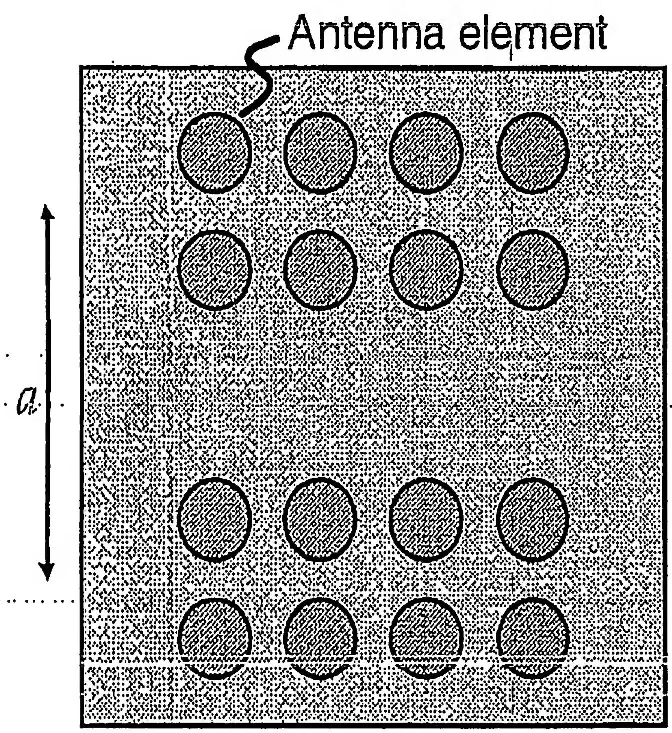

Fig. 11

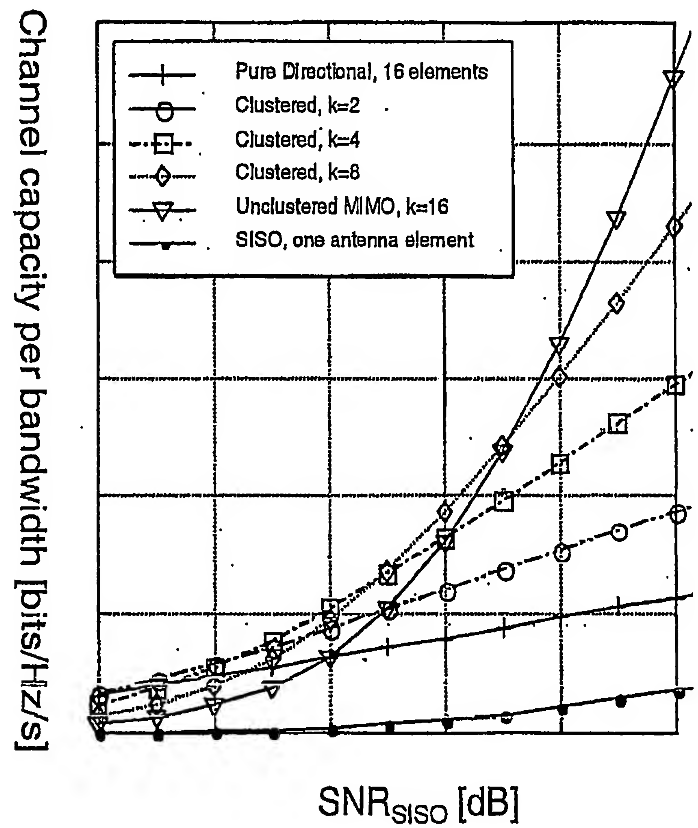

Fig. 12

PCT / SE 2003 / 002081
+46 8 ?5? 56 95

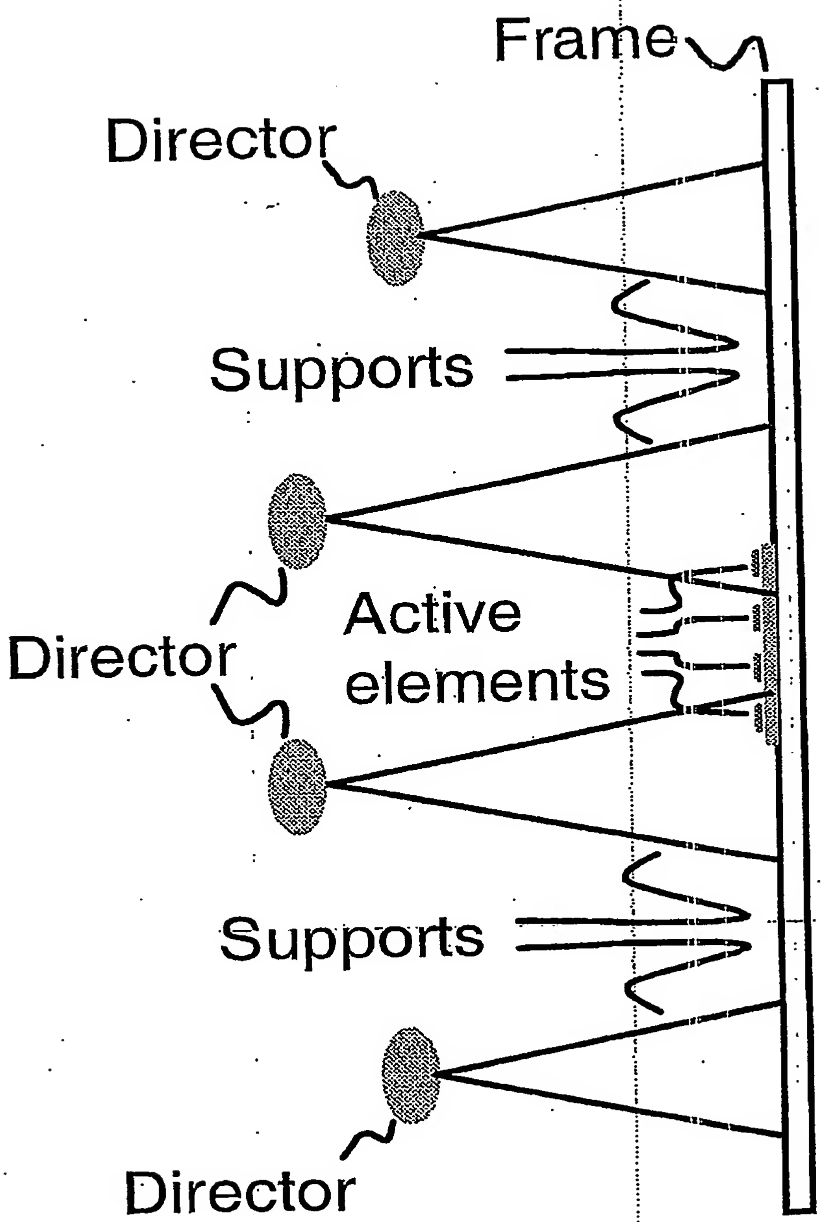
Frame
Director
Supports
Director
Active elements
Supports
Director

Fig. 13

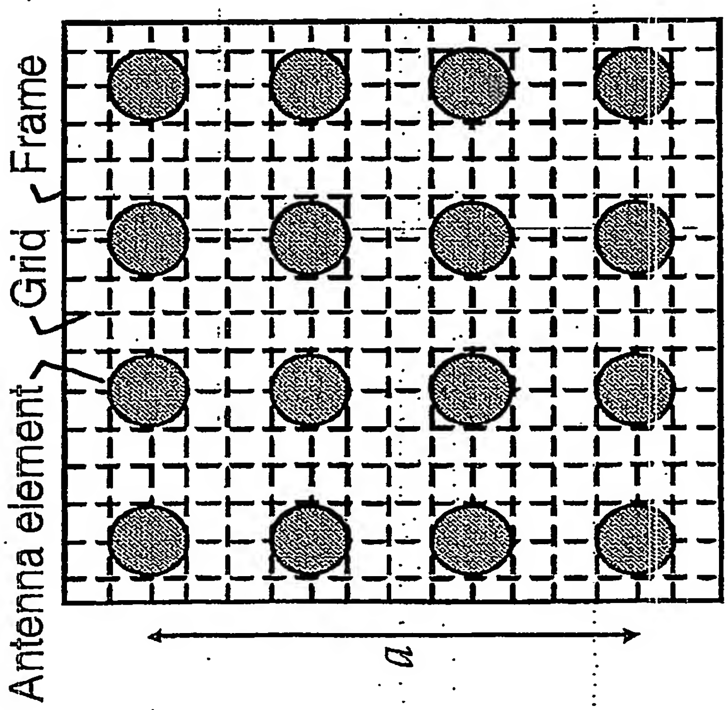

Fig. 14

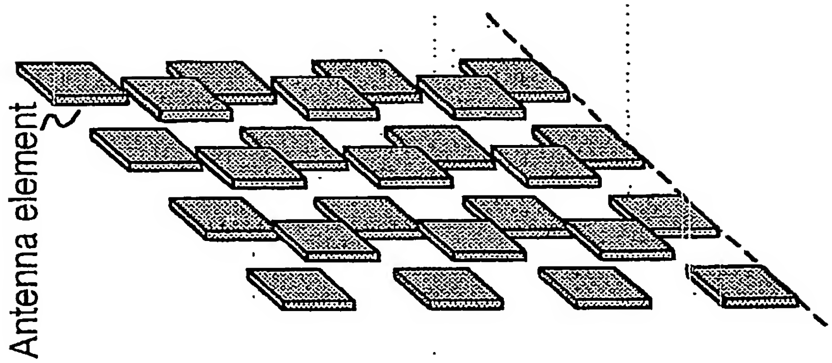

Fig. 15

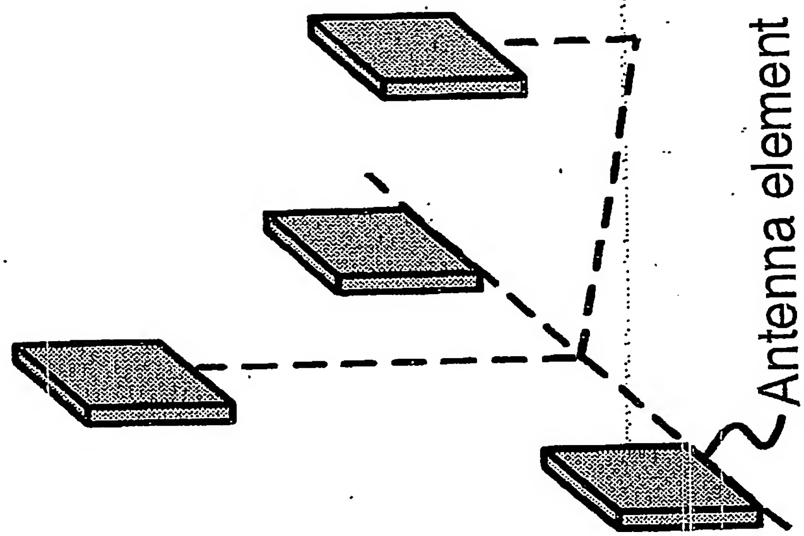

Fig. 17

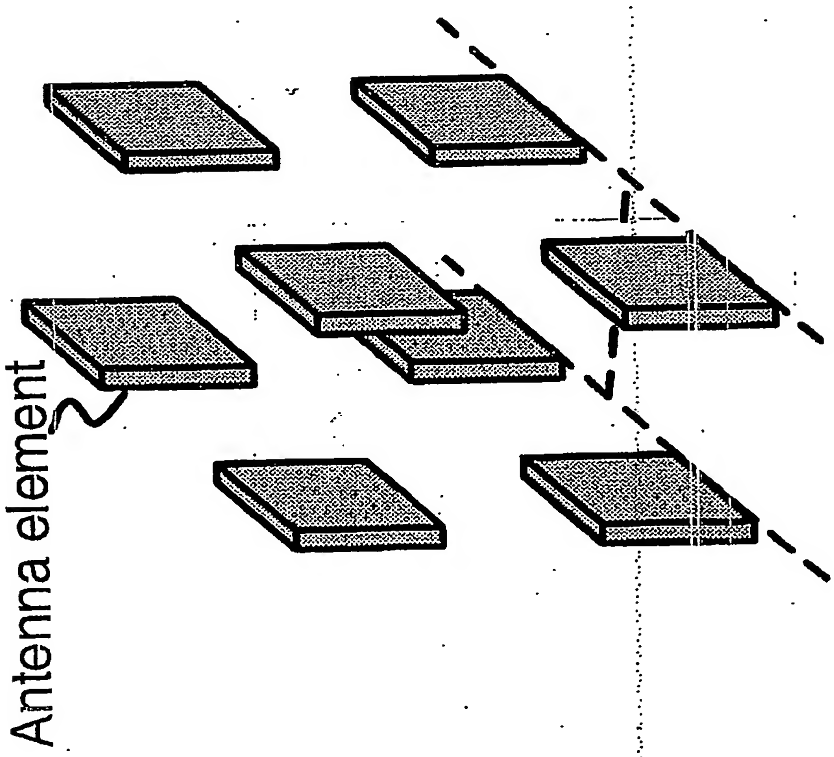

Fig. 16

Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/SE04/001952

International filing date: 21 December 2004 (21.12.2004)

Document type: Certified copy of priority document

Document details: Country/Office: SE
Number: PCT/SE03/02081
Filing date: 22 December 2003 (22.12.2003)

Date of receipt at the International Bureau: 10 January 2005 (10.01.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)